Article Identifier
DOI: 10.22032/dbt.58670
URN: urn:nbn:de:gbv:ilm1-2023isc-080:7

60th ILMENAU SCIENTIFIC COLLOQUIUM Technische Universität Ilmenau, 4 – 8 September 2023 URN: urn:nbn:de:gbv:ilm1-2023isc:1

How reliable are *optical* measurements of surface roughness?

T. Dziomba[1], A. Felgner[1], S. Gao[1], M. Hemmleb[2], M. Ritter[3], E. Gärtner[4], J. Frühauf[4]

[1] Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany
[2] point electronic GmbH, Erich-Neuß-Weg 15, 06120 Halle/Saale, Germany
[3] Technische Universität Hamburg, Eißendorfer Straße 42, 21073 Hamburg, Germany
[4] SiMETRICS GmbH, Am Südhang 5, 09212 Limbach-Oberfrohna, Germany

E-Mail: thorsten.dziomba@ptb.de Phone: +49 531 592-5122

Roughness measurements belong to the most important and most frequently performed dimensional measurements for quality control in industry: The roughness of a surface is often decisive for the function of a workpiece, and subsequently, roughness measurements are not only applied in the development and prototype stage, but also in the production chain in many branches of precision engineering. Consequently, the correct measurement of roughness and the accounting of roughness influences belong to the main research directions in dimensional metrology.

Stylus profilometry is routinely used for roughness measurements for many decades already and allows reliable, traceable measurements since standards had been introduced in this field more than 30 years ago. However, this technique is long known to reach its limits: Firstly, the lateral resolution is limited by the tip radius, which is typically not smaller than 2 µm, and secondly, it mainly remains a profile method only, as it is time-consuming to record an areal topography image. The latter, however, is urgently needed in many fields, as directional dependencies and anisotropic roughness properties are decisive e. g. for sliding properties or the propagation of liquids and films on surfaces.

Optical surface measurement techniques, such as confocal laser scanning microscopy (CLSM), white-light interference microscopy (WLI) and focus variation, are therefore highly appreciated not only in academia, but in many fields of industry as well for their fast, non-contact and areal topography measurements. With the ongoing miniaturization and shift from micro- and nanofabrication, atomic force microscopy (AFM) comes into play for highest-resolution roughness measurements.

The progress in the field of (optical) surface measurement techniques drives the corresponding international standardization in ISO/TC 213 /WG 16 “Areal and profile surface texture”, while a number of material measures, specified in its ISO 25178-70, is currently being developed for the required thorough verification and calibration of areal measurement instruments.

However, many optical surface measurements still lack comparability: While the calibration of the measurement axes is usually accomplished well by traceable lateral and depth-setting standards, the characterization of the instruments’ roughness measurement capabilities is still a challenge: Apart from the measurement mode and its particular realization, hardware such as the used optical objectives (numerical aperture and other properties), image formation and implemented data-processing have a huge impact on the measured topography. This was recently confirmed e. g. by the EURAMET comparison 1242 on surface roughness among European National Metrology Institutes (NMI), piloted by PTB: On surfaces with a higher-frequency roughness (with constituting spatial wavelengths of 1 or few µm) and significant slopes (>20°), measurements results were found to deviate by up to 70 % even for mean roughness parameters such as Sa or Sq! This shows that much work needs to be done to achieve more comparability and ultimately traceability for such roughness measurements, both by NMIs and guideline/standardization organizations. The parallel EURAMET comparison 1239 on AFM roughness measurements is currently in progress.

For this reason, intensive investigations of the influencing factors have started at PTB. Apart from noise and spatial resolution, the so-called topography fidelity needs to be assessed, e. g. by a set of instrument transfer functions (ITF) that, additionally, show a strong dependence on *z*-amplitudes and slopes. Apart from the spatial frequencies that constitute the surface texture of a workpiece, it is particularly the slope that decides whether a surface can be reliably measured by a certain optical technique and its hardware configuration. For example, especially in WLI, “overshoots” (batwings, outliers) often occur at slopes or asperities that lead to false higher roughness values and apparent steep slope artefacts, while CLSM usually performs better at such higher-frequency roughness (see Fig. 1 and 2 with a comparison to AFM).

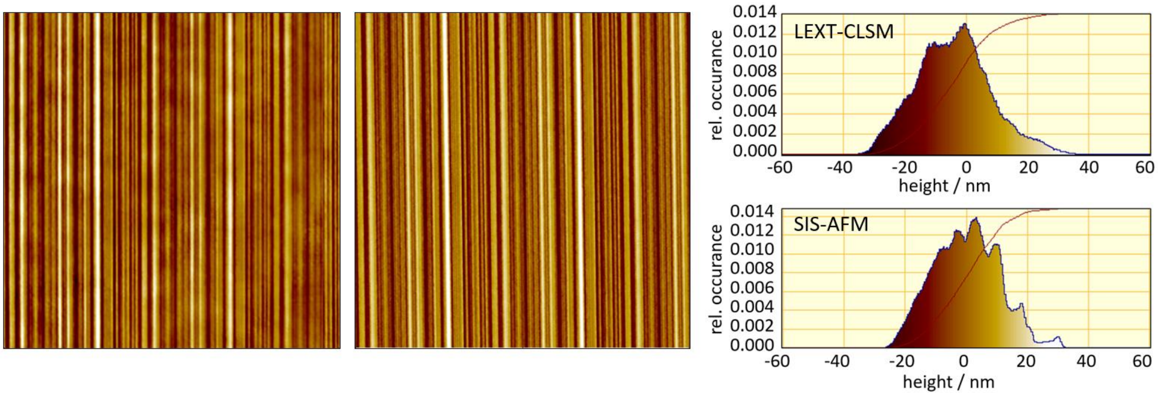

Fig. 1 The same field of 65 µm x 65 µm on an UFRS, measured by Olympus LEXT CLSM (left, 100x objective used, A_N = 0.95) and SIS AFM (centre) with same colour-coding of height (black-to-white equals 50 nm), and the corresponding height histograms (right)

	Sa	*Sq*	*Ssk*	*Sku*	*Sz*	*Spk*	*Sk*	*Svk*	*S*δ5-95
LEXT CLSM	9.6	12.0	0.24	2.9	73.1	14.7	30.7	8.7	40.6
SIS AFM	8.7	10.7	0.15	2.7	61.6	10.9	29.1	6.9	35.1

Table 1: Comparison of CLSM and AFM roughness values for the images shown in Fig. 1. *Ssk* and *Sku* dimensionless, all others in nm. Images levelled, not filtered. Roughness analysis by software SPIP (Image Metrology A/S, Denmark)

Fig. 1 shows the comparison of CLSM and AFM topography measurements at a so-called UltraFine Roughness Standard (UFRS), fabricated by Focused Ion Beam Milling (FIB). The CLSM topography image is superposed by a slight waviness and appears sharper on its left. The corresponding height histograms show a slightly broader distribution of the height values for the CLSM, which also reflects in slighter higher CLSM roughness values than the AFM reference (table 1).

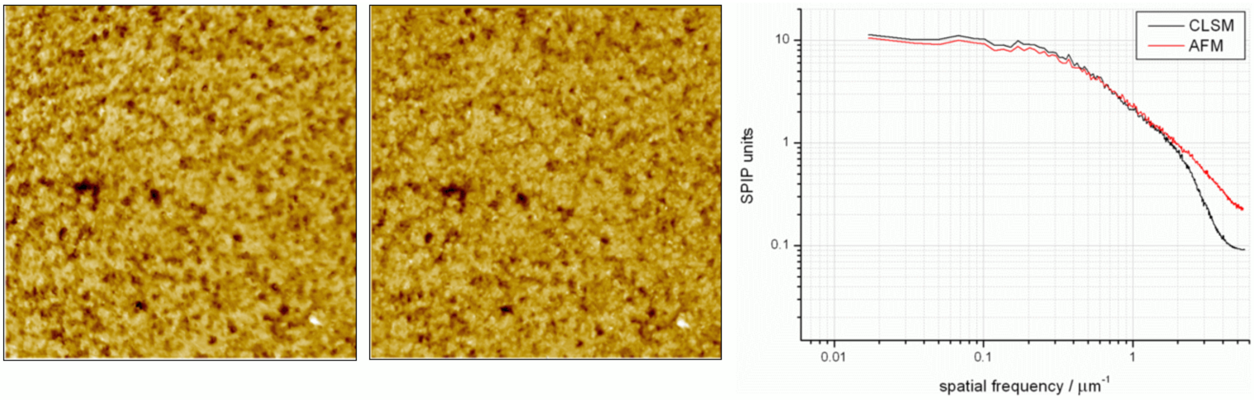

Fig. 2 The same field of 59 µm x 59 µm on a SiMETRICS ARS type f, measured by LEXT CLSM (left, 50x objective, A_N = 0.95) and SIS AFM (centre, *Sa* = 53 nm, *Sq* = 70 nm) with same colour-coding of height (black-to-white equals 1100 nm), plot of both FFTs (right)

Fig. 2 compares CLSM and AFM at an isotropic roughness, produced by lapping at SiMETRICS GmbH. The corresponding FFT plot reveals a strong decrease starting at 2 µm^{-1} (i. e. 500 nm) for the CLSM, i. e. shorter spatial wavelengths are no longer fully transmitted in the CLSM, contrary to AFM.

This presentation will give an overview on the standardization activities and available calibration standards for areal roughness. The focus will be on these systematic investigations by comparisons of measurements on various types of roughness by different optical measurement techniques, usually with AFM as reference method, and reveal some of the typical, critical artefacts specific to CLSM or WLI to help the users find a suitable measurement technique for his particular roughness samples.

Acknowledgements

Parts of this work have received funding from the EMPIR program (20IND07, project TracOptic) co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation program.